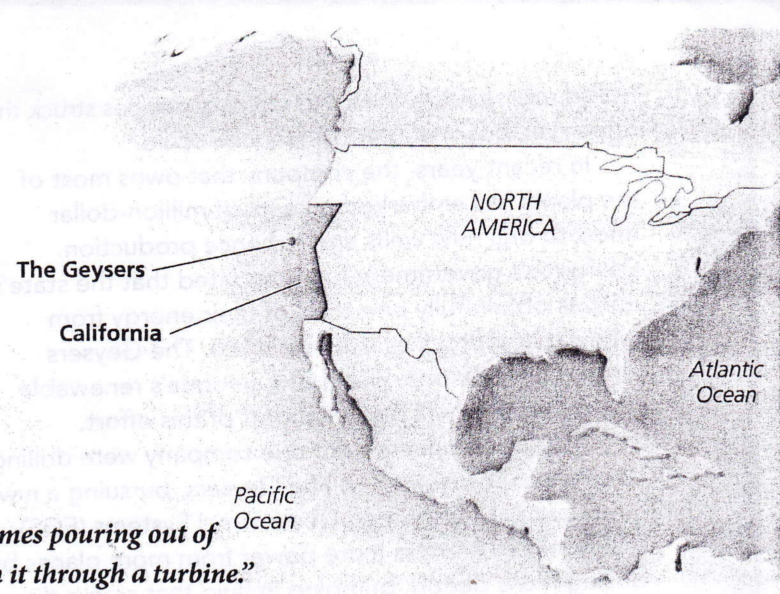
CENTRAL **CASE STUDY**

Clean Green Energy Beneath Our Feet: The Geysers in California

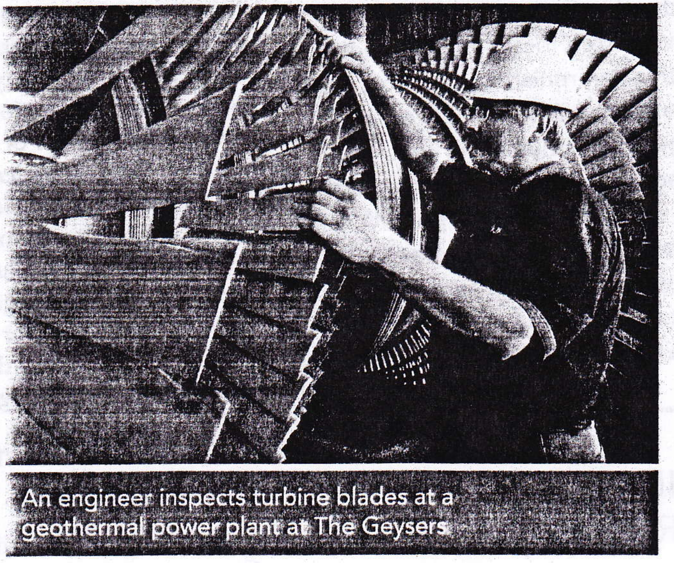


> ***"You drill a well [at The Geysers] and just pure steam comes pouring out of the ground and you don't have to do anything except run it through a turbine."***
>
> —Dr. David Blackwell of Southern Methodist University's Geothermal Lab

> ***"Enhanced Geothermal Systems could be the 'killer app' of the energy world."***
>
> —Dan Reicher, Director of Climate and Energy Initiatives for Google.org, which is funding geothermal energy research

In 1847, explorer William Bell Elliott was hunting grizzly bears in the hills of northern California when he stumbled into a bizarre valley full of hissing jets of steam, sputtering sulfurous vents, and bubbling hot springs. He likened the scene to "the ruins of a recently burned city" and "the gates of hell."

A century and a half later, the spouting vapors in this region that he named "The Geysers" are providing renewable energy for modern residents of the region. For in these hills north of San Francisco, just beyond the wineries of the Napa and Sonoma valleys, rocks deep underground get so hot that water turns to steam. By tapping into these reservoirs of trapped steam, engineers at a complex of geothermal power plants—also called The Geysers—are producing enough electricity to power nearly a million homes.



An engineer inspects turbine blades at a geothermal power plant at The Geysers

Geothermal energy (from the Greek *geo* for "Earth" and *therme* for "heat") is thermal energy from below Earth's surface. At the site of The Geysers, magma (molten rock) rises relatively close to the surface, keeping the underground rock unusually hot. A *geyser* is a location where hot water and steam spout out of the ground, forced up naturally by pressure. There are, strictly speaking, no geysers at the site of The Geysers—only *fumaroles*, spouts of steam or other gases. Yet since 1921, people have tapped this area for its geothermal energy by extracting steam created by the underground heat and using it to turn turbines to generate electricity. Today the 22 power plants at The Geysers generate more geothermal power than anywhere else in the world.

However, there was a problem. The power plants were drawing up steam more quickly than it was being replenished underground, and although the plants returned some water to the ground, they were gradually depleting the subterranean reservoirs. Power production peaked in 1987 and then began declining as the groundwater supply dwindled.

In response, the managers began to import treated wastewater from surrounding communities and inject it into the ground. The idea was to replenish the aquifer to sustain the steam supply, while also doing a service for the communities. These efforts—the first of their kind in the world—seem to be working. The injected water has replenished the groundwater supply, and power generation is proceeding apace at stable levels.

Another problem has emerged, though: earthquakes. Extracting steam from underground and pumping water into the ground changes subterranean pressures in ways we cannot accurately predict—and changing pressures can cause earthquakes. Indeed, since the 1970s the area has been beset with flurries of small earthquakes (called microearthquakes). No major quake has struck the region yet, but many people fear one could.

In recent years, the company that owns most of the plants has embarked on a multi-million-dollar effort to drill new wells and enhance production. California's government has mandated that the state's utilities obtain fully one-third of their energy from renewable sources by the year 2020. The Geysers already provide one-fourth of California's renewable energy, so they will be a vital part of this effort.

In 2009, engineers from one company were drilling deeply into the ground at The Geysers, pursuing a new strategy called Enhanced Geothermal Systems (EGS). EGS seeks to harness more power from more places by drilling more deeply, pumping in fluid that cracks the rocks and becomes readily heated, and then drawing up the heated fluid. However, in Europe some EGS projects have been shut down after they appeared to generate earthquakes. At The Geysers, the project proceeded amid public concern over earthquakes but was suspended when the drill got stuck less than halfway to its intended depth.

As we try to move away from fossil fuels and begin powering our society with clean renewable energy, we are looking to the sun, to the wind, to the waves, and to the geothermal energy right beneath our feet. But if the price of abundant geothermal power is more earthquakes, that's a price we might not want to pay. We can hope and expect that more scientific study, creative technology, and public input can help us surmount the challenges that lie between our fossil fuel economy of today and the renewable energy future of tomorrow.

MATTER, CHEMISTRY, AND THE ENVIRONMENT

Geothermal heating arises from the interplay of rock, water, and heat. It involves geology, chemistry, and energy, and it is a process that takes place on a large scale. Environmental scientists regularly study these types of processes to understand how our planet works. Because all large-scale processes are made up of small-scale components, however, environmental science—the broadest of scientific fields—must also study small phenomena. At the smallest scale, an understanding of matter itself helps us to fully appreciate all the processes of our world.

All material in the universe that has mass and occupies space—solid, liquid, and gas alike—is termed **matter.** In our quick tour of matter in the pages that follow, we examine types of matter and some of the important ways they interact—phenomena that together we term **chemistry.** Once you examine any environmental issue, you will likely discover chemistry playing a central role. Chemistry is crucial for understanding how gases such as carbon dioxide and methane contribute to global climate change, how pollutants such as sulfur dioxide and nitric oxide cause acid rain, and how pesticides and other compounds we release into the environment affect the health of wildlife and people. Chemistry is central, too, in understanding water pollution and wastewater treatment, hazardous waste and its cleanup and disposal, atmospheric ozone depletion, and most energy issues. Moreover, countless applications of chemistry can help us address environmental problems.

Matter is conserved

To appreciate the chemistry involved in environmental science, we must begin with a grasp of the fundamentals. Matter may be transformed from one type of substance into others, but it cannot be created or destroyed. This principle is referred to as the **law of conservation of matter.** In environmental science, this principle helps us understand that the amount of matter stays constant as it is recycled in nutrient cycles and ecosystems (pp. 115, 122). It also makes clear that we cannot simply wish away the matter (such as waste and pollution) that we want to eliminate. Any piece of garbage or drop of spilled oil or billow of smokestack pollution or canister of nuclear waste that we dispose of will not simply disappear. Instead, we will need to take responsible steps to mitigate its impacts.

Atoms and elements are chemical building blocks

The geothermally heated water that rises up as steam at The Geysers is made up of **hydrogen** and **oxygen,** each of which is an element. An **element** is a fundamental type of matter, a chemical substance with a given set of properties, which cannot be broken down into substances with other properties. Chemists currently recognize 92 elements occurring in nature, as well as more than 20 others that they have created in the lab.

TABLE 2.1 Earth's Most Abundant Chemical Elements, by Mass

Earth's crust	Oceans	Air	Organisms
Oxygen (O), 49.5%	Oxygen (O), 88.3%	Nitrogen (N), 78.1%	Oxygen (O), 65.0%
Silicon (Si), 25.7%	Hydrogen (H), 11.0%	Oxygen (O), 21.0%	Carbon (C), 18.5%
Aluminum (Al), 7.4%	Chlorine (Cl), 1.9%	Argon (Ar), 0.9%	Hydrogen (H), 9.5%
Iron (Fe), 4.7%	Sodium (Na), 1.1%	Other, <0.1%	Nitrogen (N), 3.3%
Calcium (Ca), 3.6%	Magnesium (Mg), 0.1%		Calcium (Ca), 1.5%
Sodium (Na), 2.8%	Sulfur (S), 0.1%		Phosphorus (P), 1.0%
Potassium (K), 2.6%	Calcium (Ca), <0.1%		Potassium (K), 0.4%
Magnesium (Mg), 2.1%	Potassium (K), <0.1%		Sulfur (S), 0.3%
Other, 1.6%	Bromine (Br), <0.1%		Other, 0.5%